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Channel Model Tool Based on Bidirectional Analytic Ray Tracing and Radiative Transfer (CBAR)

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AIR FORCE FLIGHT TEST CENTER
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14. ABSTRACT Test and evaluation (T&E) of airborne test articles is routinely carried out in Major Range and Test Facility Bases across United States. Critical test data is obtained through a telemetry link. The link quality, and thereby the ability to record test data at a ground station, strongly depends on the channel conditions. Typical aeronautical telemetry channels suffer from multipath fading, resulting in link dropouts or outage, and flight tests are very expensive. Therefore, a channel model tool that allows a user to understand the telemetry performance of a test article flying over a known geographical region is highly desirable.

Existing channel model capabilities are sufficient for conducting flight tests over water or flat ground such as desert and dry lake bed. However, they cannot fulfill requirements of more sophisticated test scenarios involving low flying unmanned air vehicles and helicopters tested over water at high sea states, in hilly terrain, or even over urban environment. Some of these tests may be deliberately carried out under weather conditions such as rain. Therefore, it is necessary to have an improved radio frequency channel modeling tool that faithfully capture impact of atmospheric conditions, complex terrain reflection, and foliage scattering; and quickly generate performance evaluation results.

In this project, IAI is developing a software tool called CBAR (Channel Model Tool Based on Bidirectional Analytic Ray Tracing and Radiative Transfer) that offers the benefit of high-fidelity channel characterization accounting for terrain and atmospheric effects, resulting in statistical and deterministic channel models that can be incorporated easily into a wireless network performance simulation tool. The key components of CBAR are as follows:

1. A fast and efficient ray-tracing tool that incorporates not only geographic effects but also geophysical properties. The airframe's effect on the telemetry antenna pattern can also be incorporated.
2. A statistical modeling approach that can generate properties of a wireless channel such as multipath delay spread and propagation path loss for a given geographical area.
3. A bit error rate evaluation tool that allows a user to measure performance characteristics of communication schemes commonly used for telemetry. Performance evaluation for single carrier serial streaming schemes using pulse-coded modulation/frequency modulation (PCM/FM) and shaped-offset quadrature phase-shift keying (SOQPSK) is implemented initially. Multicarrier and other integrated network-enhanced telemetry (iNET) communication schemes will be added later.
4. A professional 3D graphical user interface that allows users to interactively design the scenario and visualize the simulation process. The tool can accept Digital Terrain Elevation Data (DTED) for the terrain and computer-aided design (CAD) model for the test article. Given aircraft characteristics and way points, the tool can generate realistic trajectory and attitude profile.

CBAR has the potential to help the T&E community to reduce the cost of mission planning and increase the chance of successful tests. It can also be used for airborne/ground station telemetry antenna selection and placement to meet the requirement of different missions. Finally, CBAR can help T&E select the most appropriate telemetry communication scheme to ensure reliable test data collection.

15. SUBJECT TERMS shaped-offset quadrature phase-shift keying (SOQPSK), telemetry, spectrum, channel model tool,

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Channel Model Tool Based on Bidirectional Analytic Ray Tracing and Radiative Transfer (CBAR)

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T&E Need

- Improved channel model to characterize aeronautical channel model in complicated scenarios, such as low flying unmanned aerial vehicles and helicopters over water at high sea states, or in hilly terrain.

- The need for performance evaluation software that can predict the communication performance when operating using telemetry waveforms.

- The need for an interactive user interface and dynamic 3D visualization software that will allow the designer to define a particular test scenario as well as visualize the simulation process.

Challenge

- Channel modeling for aeronautical telemetry involves electrically large objects/scene, therefore requiring a highly efficient 3D ray tracing algorithm in order to minimize the computational load.

- A range of physics-based electromagnetic EM models are needed that are based on strict theories such as the Maxwell's equations.

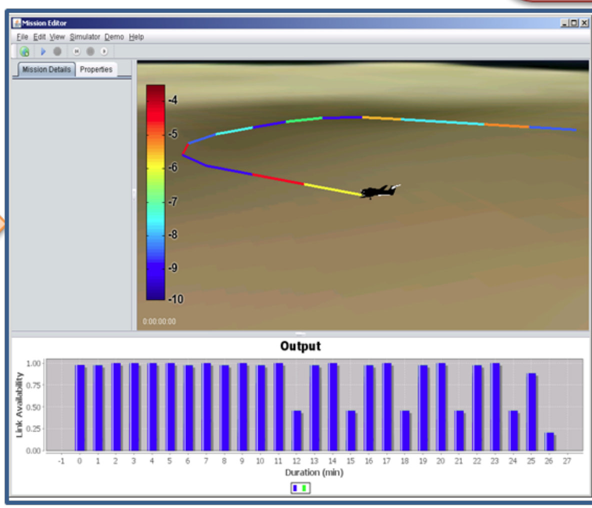
- A dedicated communication performance evaluation tool is needed to evaluate the performance of telemetry waveforms such as ARTM Tier-0 (PCM/FM) and ARTM Tier-1 (SOQPSK-TG), as well as as integrated Networking Enhanced Telemetry (iNET) standards, in relevant environments.

CBAR Overview

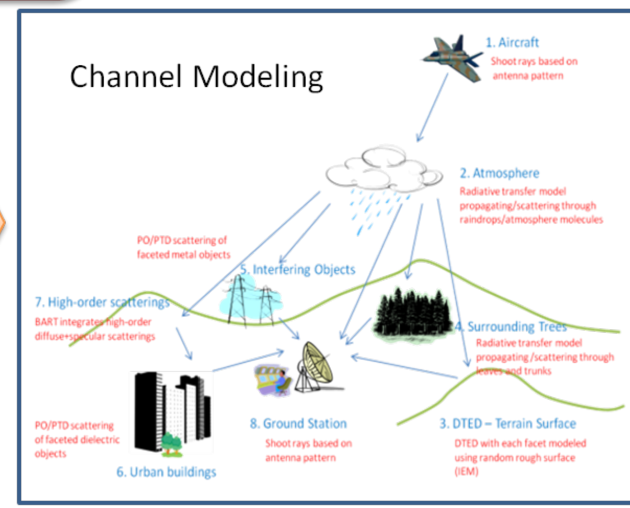
DATA

- Antenna
- Environment
- Modulation
- Route
- Terrain
- Channel Model
- Communication Performance

User



Main Control



Communication Waveforms	Performance Evaluation
SOQPSK PCM/FM CPM OFDM	Transmitter ↓ Multipath Channel ↓ Receiver

Components of CBAR

CBAR is designed to have the following features:

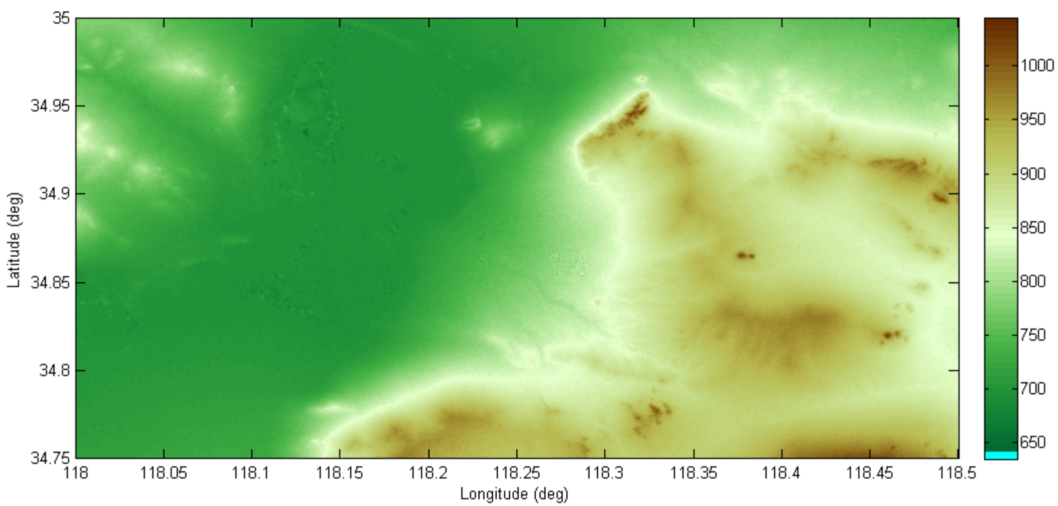
1. A ***channel modeling component*** that combines information about the environment, antenna patterns of the aircraft and ground link to generate channel impulse response for an aircraft to ground link in L, C and S bands.
2. A ***communication performance estimation component*** that utilizes channel impulse response information to estimate telemetry performance metrics such as bit error rate and link availability for modulation schemes such as SOQPSK, PCM/FM and OFDM.

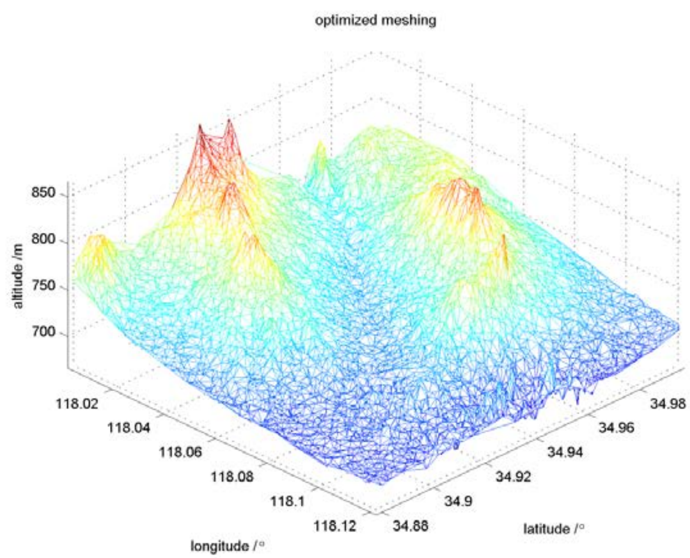
Components of CBAR, cont.

3. A ***user interface*** that allows users to specify simulation conditions such as ground station location and aircraft flight path, as well as edit analysis parameters such as link availability threshold.
4. A ***visualization component*** that displays information such as the flight path and communication performance metrics, as well as provide user with three-dimensional handles to view the simulation environment.

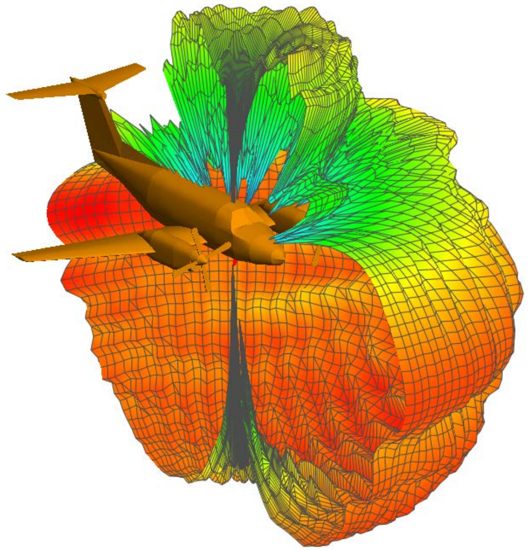
Channel modeling: Loading Terrain Data

- CBAR uses terrain data encoded in the Digital Terrain Elevation Data (DTED) format.
- CBAR will select the appropriate terrain data automatically based on the selected GCS location and the flight path.
- Terrain data is remeshed by CBAR for efficient ray tracing.

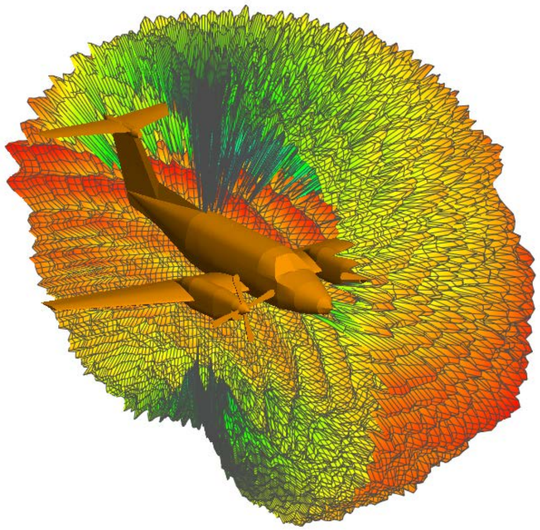




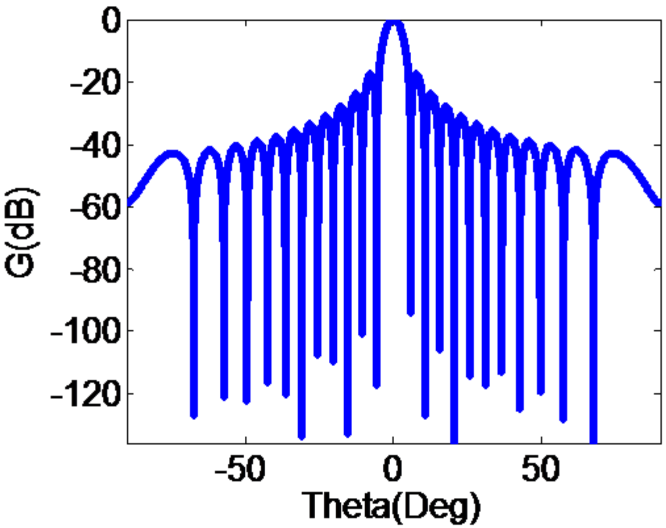
Channel Modeling : Antenna Pattern



C12 with bottom antenna

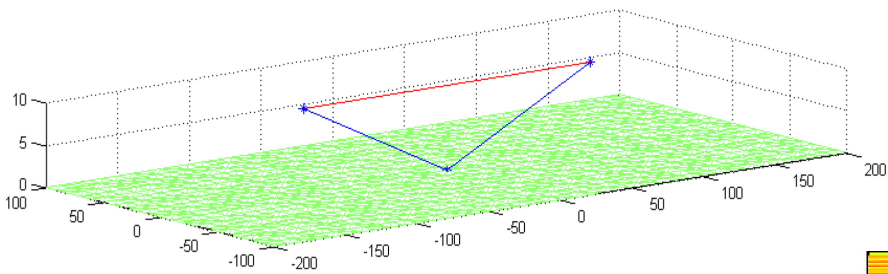


C12 with top and bottom antennas (20:80)

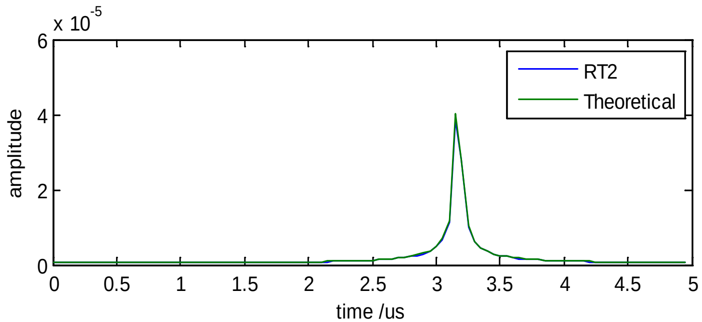


Ground station 8-ft parabolic reflector antenna pattern

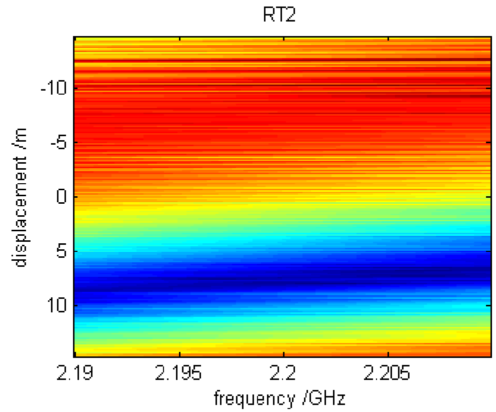
Channel Modeling: Ray Tracing Examples -- Flat Terrain

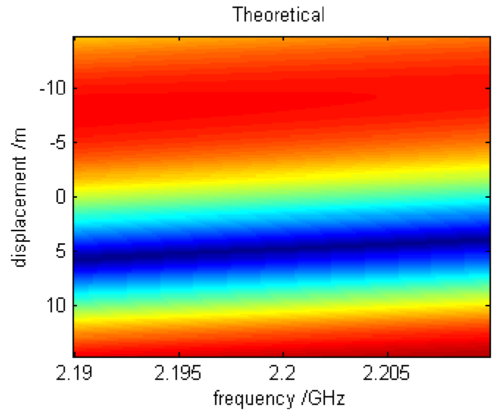


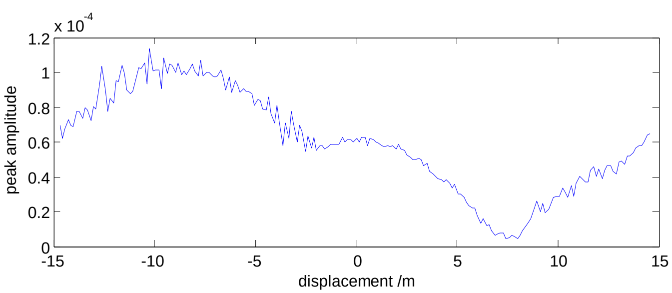
Flat surface (200m*100m). Tx and Rx are located 10m above ground with 200m horizontal separation.
Center frequency is 2.2GHz with 20MHz bandwidth.
Omnidirectional patterns are assumed both for Tx and Rx.



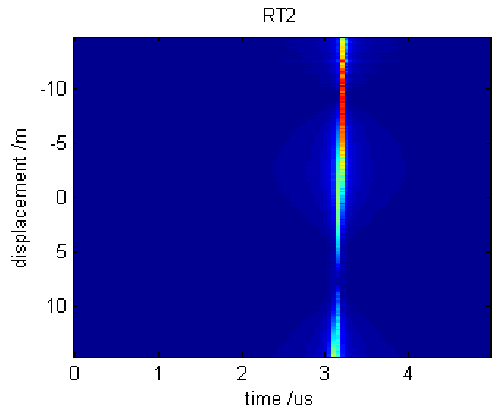
Cross section at 0m displacement

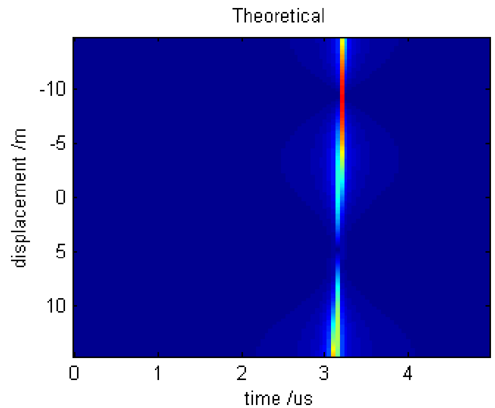




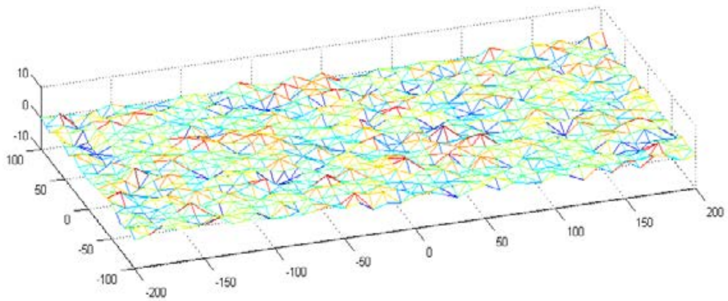


Peak amplitude vs. displacement

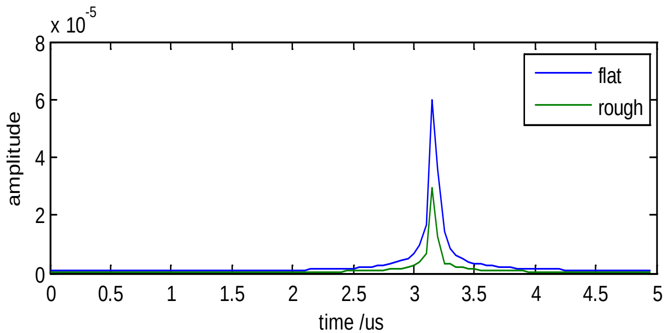


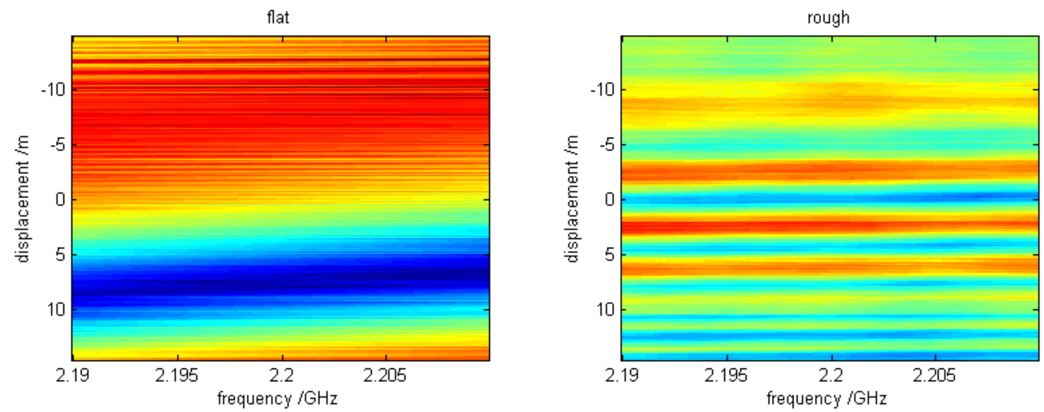


Channel Modeling: Ray Tracing Examples -- Rough Terrain

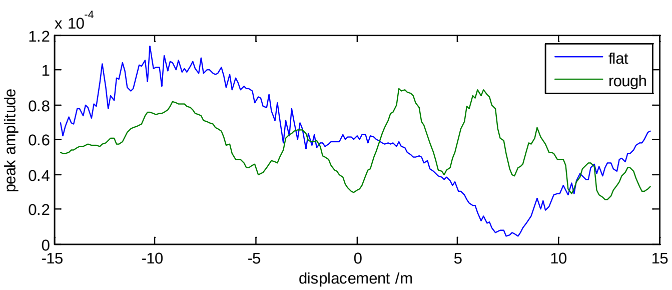


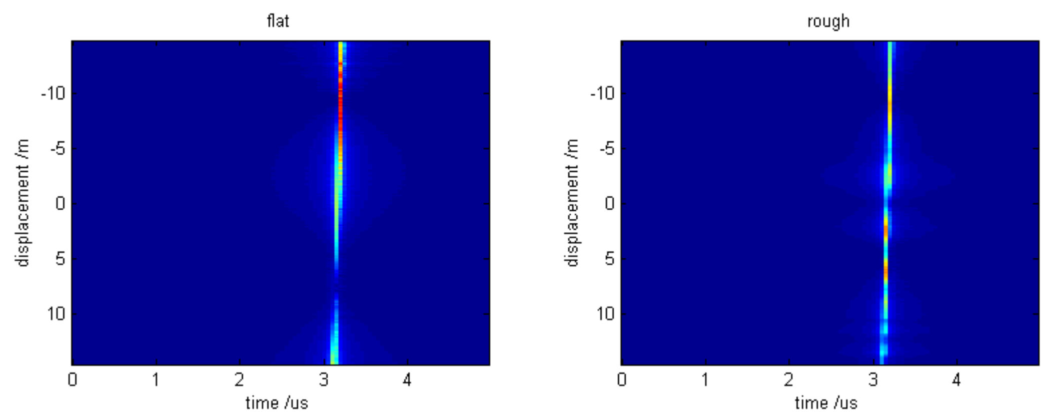
Same ground mesh with z coordinates of each node perturbed by a Gaussian random number with variance of 2m





Cross section at 0m displacement.

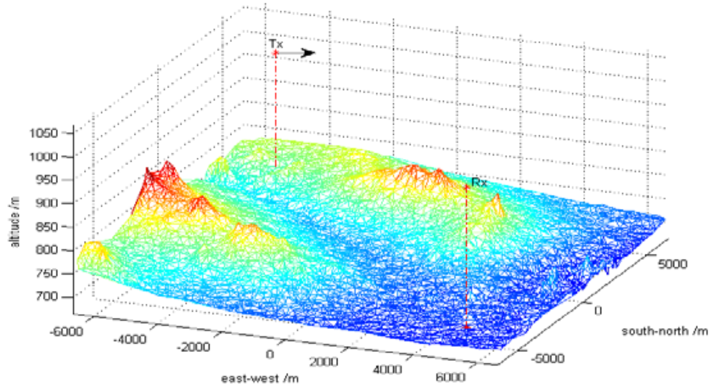


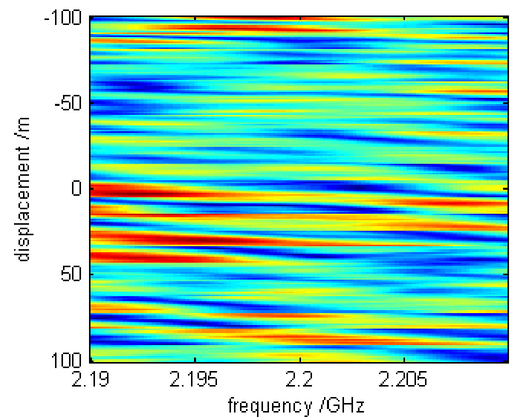


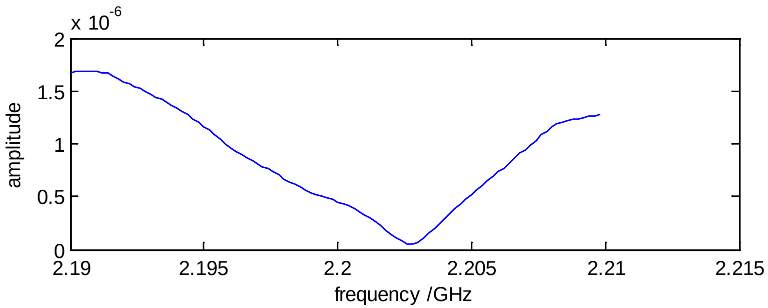
Peak amplitude vs. displacement

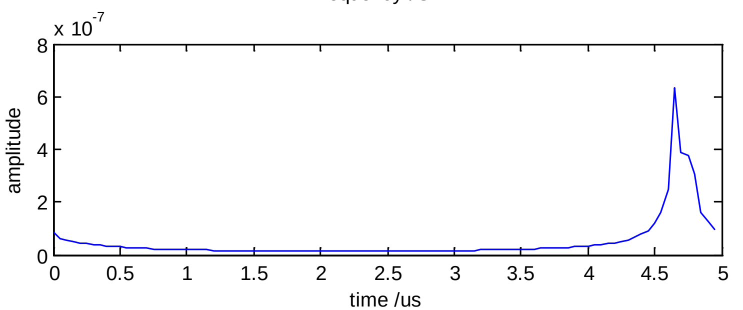
Channel Modeling: Ray Tracing Examples -- Realistic Terrain

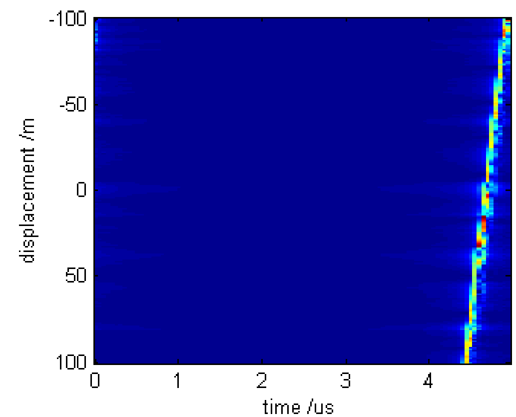
10km by 10km centered at (34.9369°, 118.0628°) (near Edwards AFB)









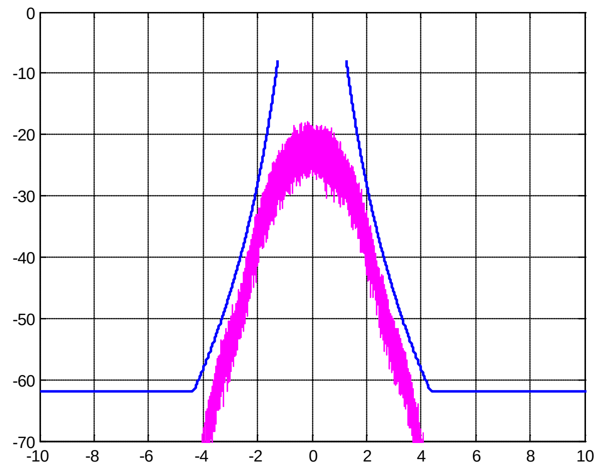


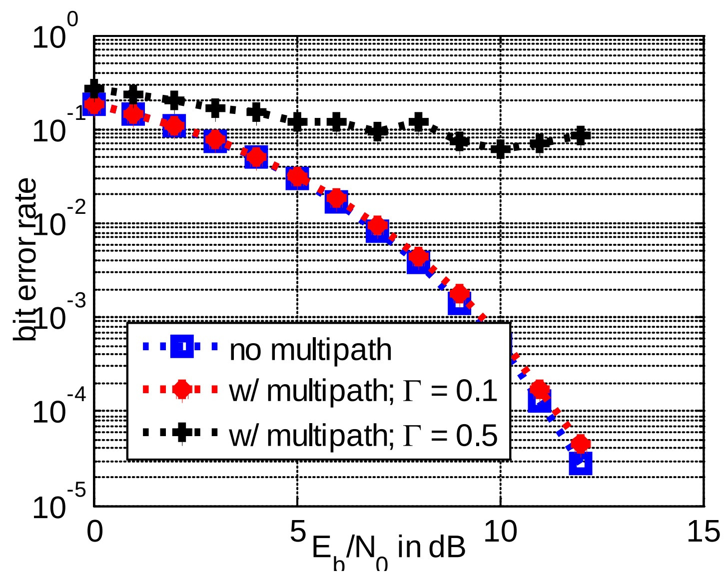
Cross section at 0m displacement

Communication Performance

- SOPQSK and PCM/FM transmitter and receiver models based on the MATLAB codes developed by Prof. Erik Perrins of Kansas University. Modified by IAI to study the BER performance under a variety of channel conditions, such as line-of-sight, multi-path, Doppler shift.
- The receiver for SOQPSK consists of a timing and frequency synchronization, followed by symbol-by-symbol detection and frame synchronization.
- The receiver for PCM/FM consists of a limiter-discriminator, followed by timing synchronization, decoding and frame synchronization.
- iNET-like OFDM transmitter and receiver models have been developed by IAI.

Spectrum and spectral mask for SOQSPK

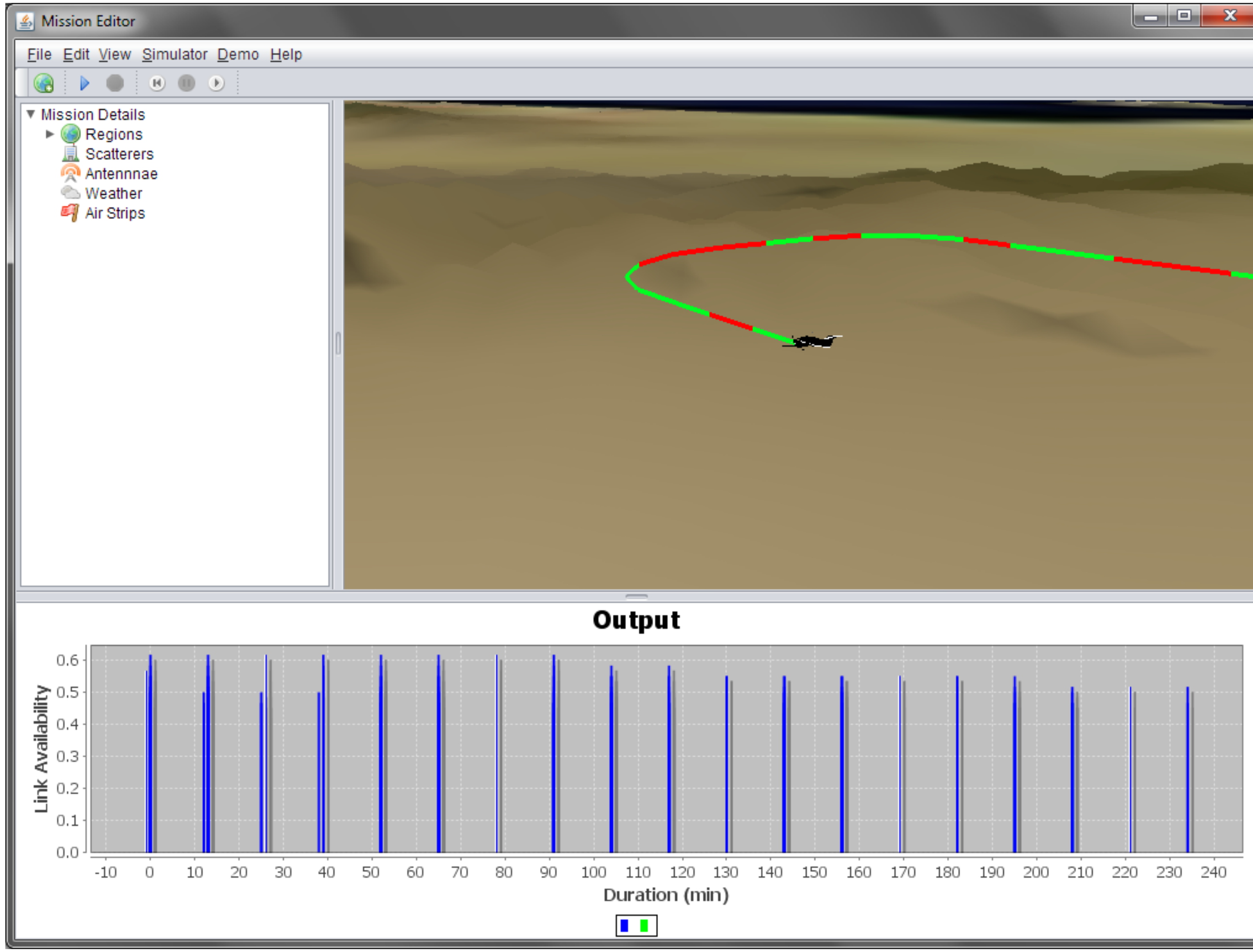




Performance of SOQPSK in the presence of multipath.

Visualization

- The flight path is colored to indicate the regions of varying link availability.
- Link availability is the percentage of time the quality exceeds a threshold.

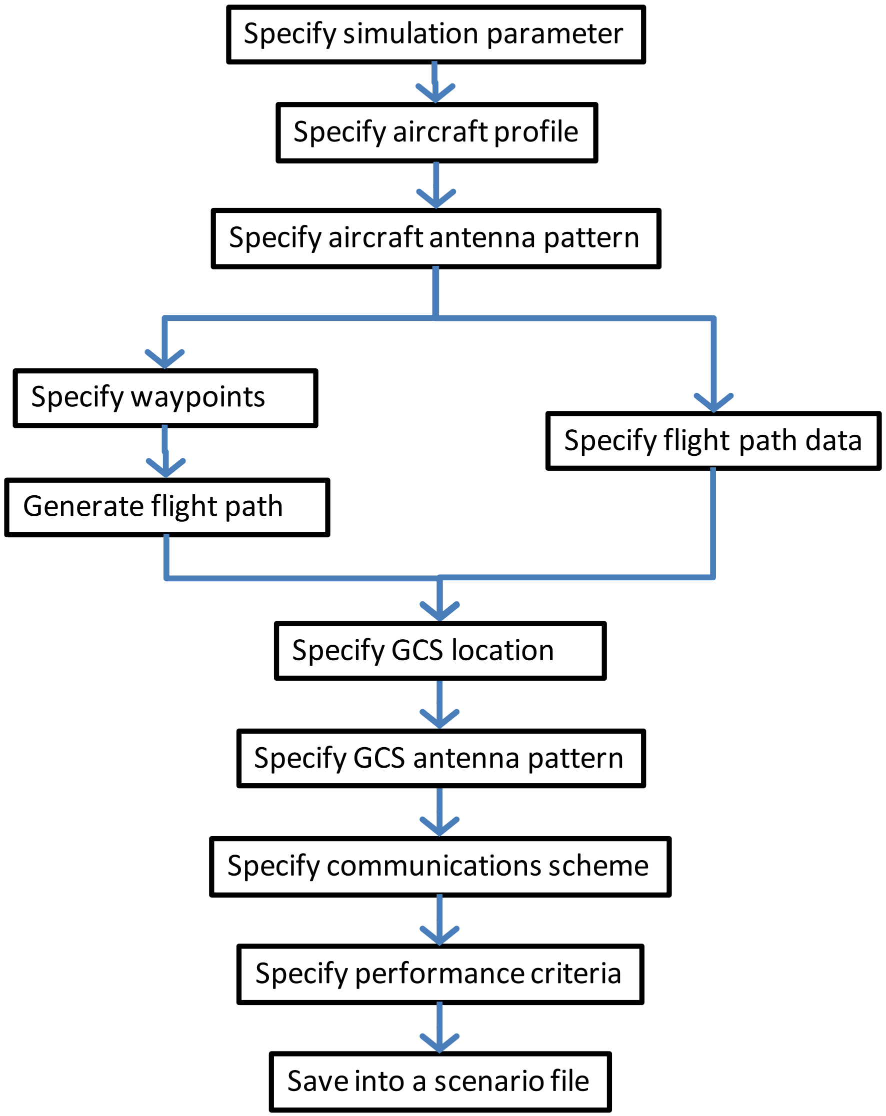


Typical use cases and operations

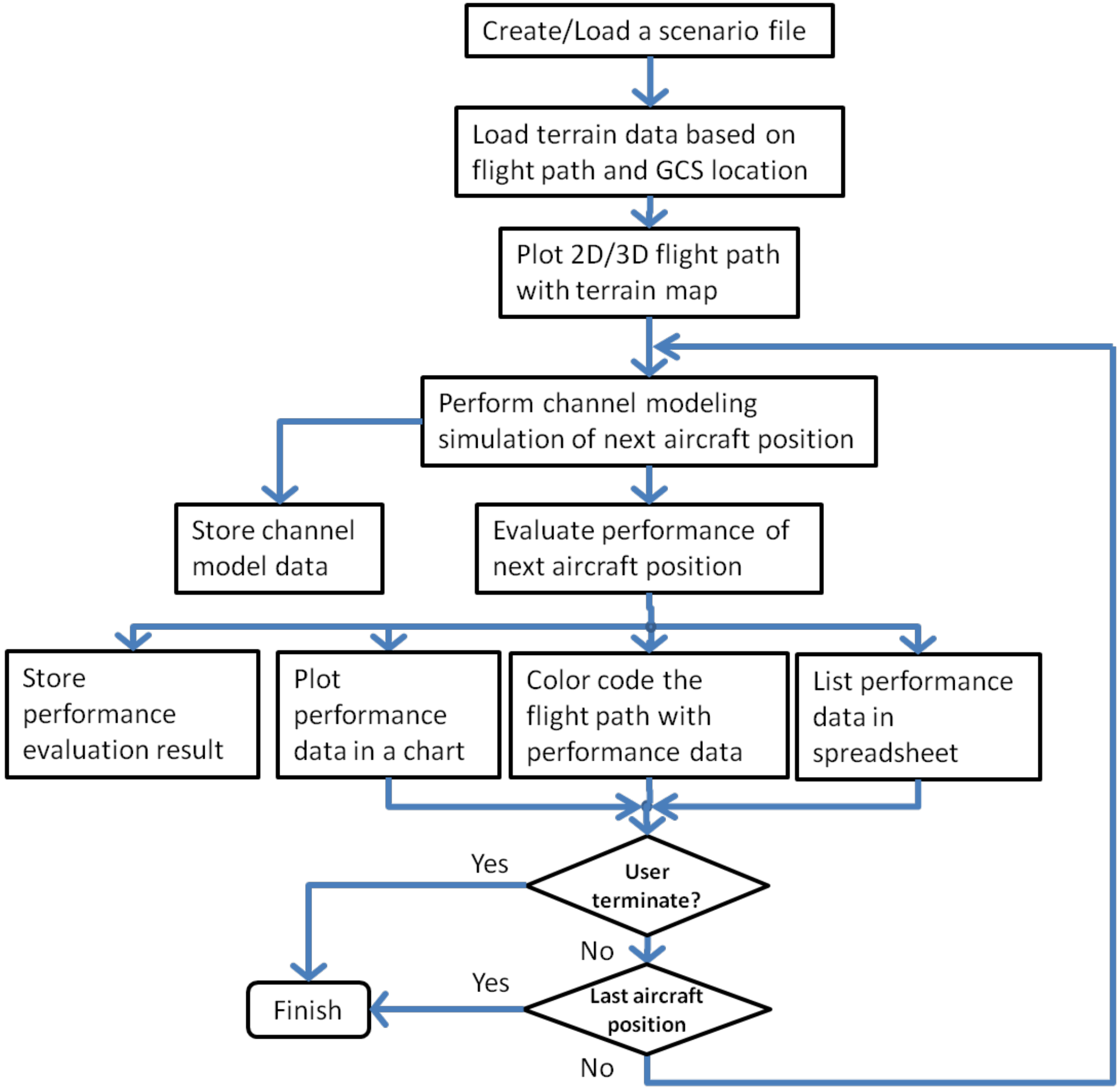
- **Step 1: Generate a scenario file with appropriate configuration parameters.**
- **Step 2: Run simulation for the entire mission duration in desired time-steps.**
- **Step 3: Evaluate communication performance, identify flight segment(s) with poor performance, and re-run the simulation focusing on the relevant segment(s).**

Step1: Generate scenario file

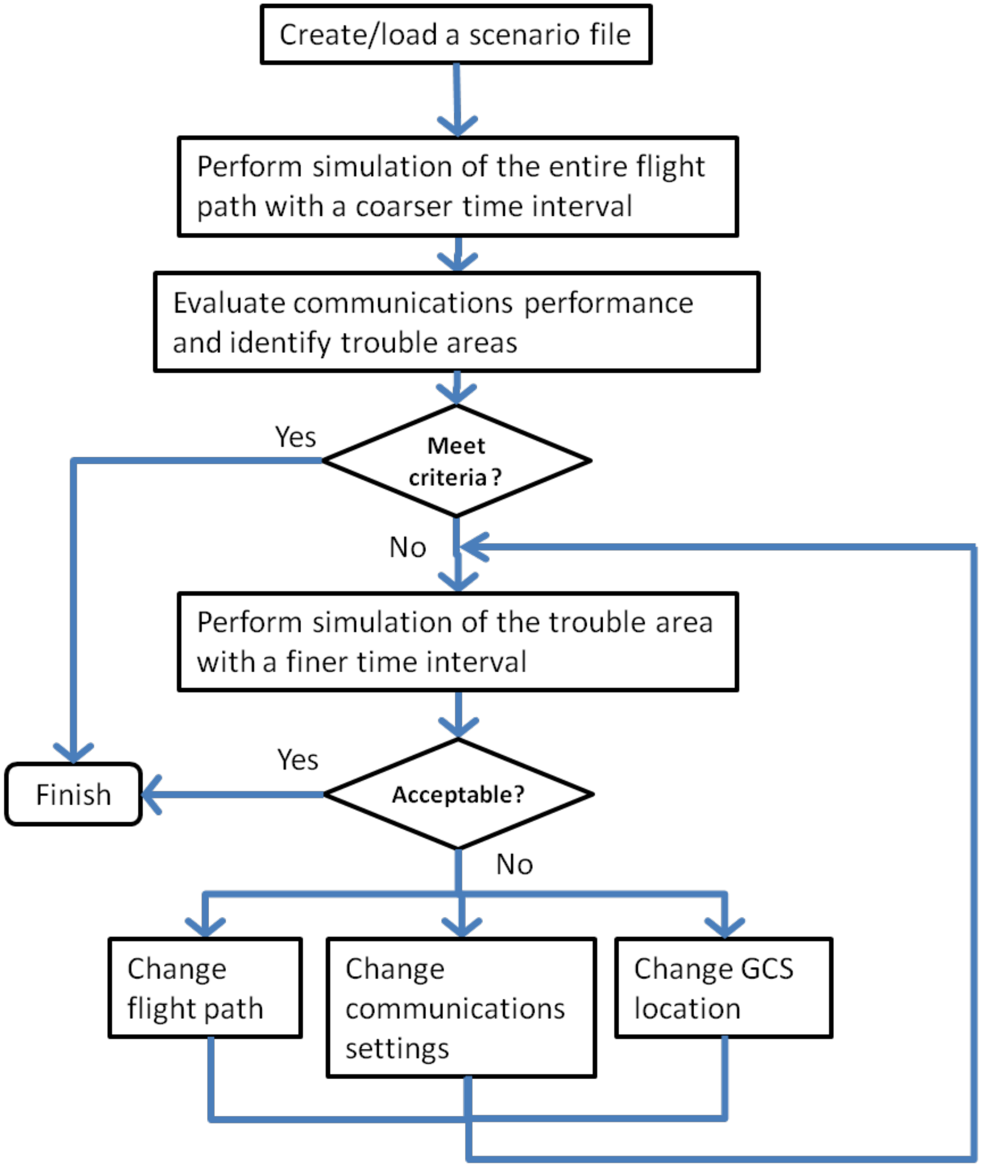
Scenario file is a file that contains important simulation properties such as aircraft and ground station configuration, aircraft flight path, channel modeling fidelity, and communication performance parameters.



Step 2: Run Simulation



Step 3: Evaluate performance and re-run simulation



Wrap Up

- A fast and efficient ray-tracing tool that incorporates not only geographic effects but also geophysical properties.
- A statistical modeling approach that can generate properties of a wireless channel such as multipath delay spread and propagation path loss for a given geographical area.
- A bit error rate (BER) evaluation tool that allows a user to measure performance characteristics of communication schemes.
- A professional 3D GUI that allows users to interactively design the scenario and visualize the simulation process.